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WHOLE-BODY VIBRATION OF STANDING SUBJECTS

Robert E. Chaney

The Boeing Company
Wichita Branch

August 1965

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WHOLE-BODY VIBRATION OF STANDING SUBJECTS

HUMAN FACTORS
TECHNICAL REPORT
D3-6779

AUGUST 1965

OFFICE OF NAVAL RESEARCH
CONTRACT NONR 2994(00)

THE BOEING COMPANY
MILITARY AIRPLANE DIVISION
WICHITA BRANCH

WHOLE-BODY VIBRATION
OF STANDING SUBJECTS.

Robert E. Chaney.

Research Accomplished Under
Office of Naval Research
Contract Nonr 2994(00)

Research On
Low Frequency Vibration Effects
On Human Performance

Principal Investigator
J. E. Beaupeurt

HUMAN FACTORS STAFF

THE BOEING COMPANY
Wichita, Kansas

D3-6779 August 1965

ABSTRACT

Five male volunteers were utilized in a study of subjective response to vibration while in the standing position. Four reaction levels (perceptible, mildly annoying, extremely annoying and alarming) were established in the range of 1 through 27 cycles per second utilizing the Boeing Human Vibration Facility as the test instrument. Experimental procedures and controls were identical to a previous study in which the subjects were seated.

The "annoying" levels established were at higher acceleration input values than their counterparts of the seated studies, with only minor variations in the "perceptible" and "alarming" curves under the two conditions. Possible explanations of the noted differences, physiological effects of vibration on the standing subject, and body absorption characteristics and their relationship to the subject's reactions are discussed.

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INTRODUCTION

Research efforts in the area of whole-body vibration, have followed, to a great extent, the evolution of the vehicle industry: from the vibrations typical of ground vehicles, through the high frequencies associated with propeller driven systems, to the low frequencies encountered in flight turbulence and space vehicles, etc. In nearly all cases, emphasis in these studies has been placed on vibration encountered while in the typical position of the operator of the various vehicles, that is, with the individual seated. Results of the studies, which include several conducted at this facility, have fairly well defined vibration levels to which the seated operator will demonstrate a given subjective response.

In keeping with the progress currently being made in the transportation field through the development of nuclear powered surface ships, hydrofoil craft, etc., there is a need for additional studies, similar to those conducted on the seated subject, to be performed with the subject standing. This effort was directed toward that end.

The purpose of the present experiment was to obtain definitions of the levels of vibration required by standing subjects to elicit "perceptible", "mildly annoying", "extremely annoying", and "alarming" subjective responses and to determine the relationship of these data to those obtained with the subjects seated (Chaney,[2] 1964). As in the previous study, emphasis was placed on isolating the sensation of vibration from more specific situations, such as a given work task or work environment condition.

METHOD

Experimental Subjects

The subjects for the experiment were five engineering employees of the Wichita Division of The Boeing Company who volunteered for participation in the vibration program. Three of the five had served as subjects in the establishment of subjective reaction to vibration in the seated position, another had participated in previous programs, and the fifth was naive to vibration in an experimental context. Each of the subjects was required to qualify for participation in the program by passing an extensive physical examination. Included in the examination were comprehensive blood chemistry tests, X-ray examinations of ankle, knee, hip and spine, and a complete electrocardiogram series. Age, height and weight of the subjects are shown in Table I.

Table I

Experimental Subject Data

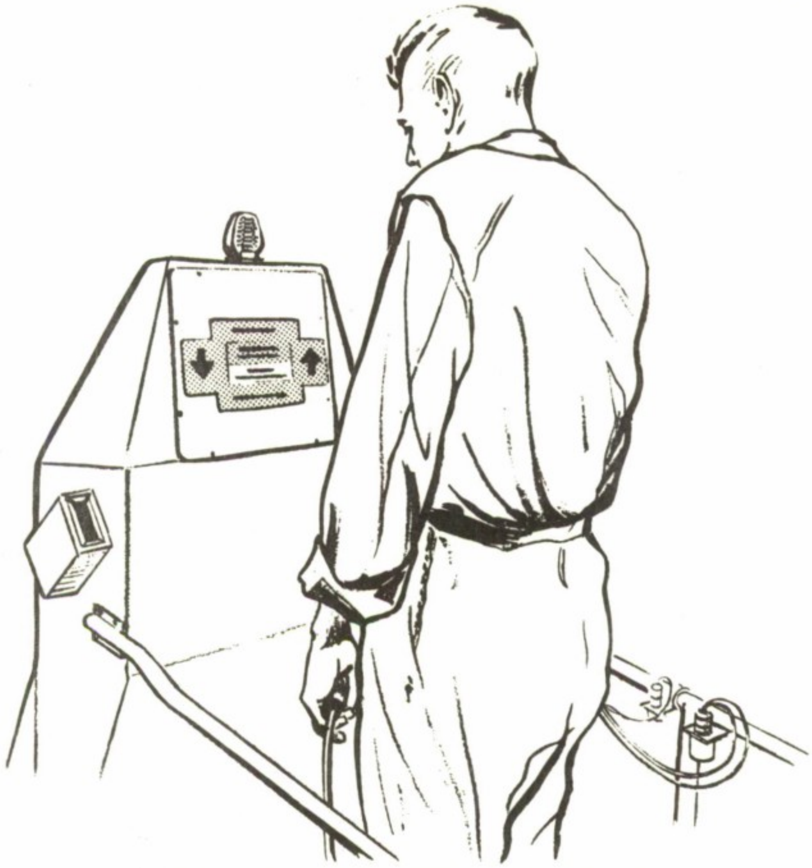
Subject #	Age	Height (in.)	Weight (lb.)
1	28	74	215
2	32	73.5	160
3	32	70.5	180
4	31	70	182
5	34	69.5	155

Apparatus

The Boeing Human Vibration Facility and associated test equipment served as the apparatus for the reported study. The facility is an electro-hydraulic vibration producing mechanism capable of moving the subject, and test console through an amplitude of 20 inches vertical displacement at 1 cycle per second (cps), and to the amplitudes necessary to produce an acceleration of 3 G's from 2 to 60 cps. The vibration platform is approximately 30 in. by 60 in. and is located in a noise-, temperature-, humidity-, and light- controlled room. The subject, while on the platform, can be observed through one-way windows in the test room. Communication between experimenter and subject is available through an intercommunication system. An illustration of the facility is shown in Figure 1.

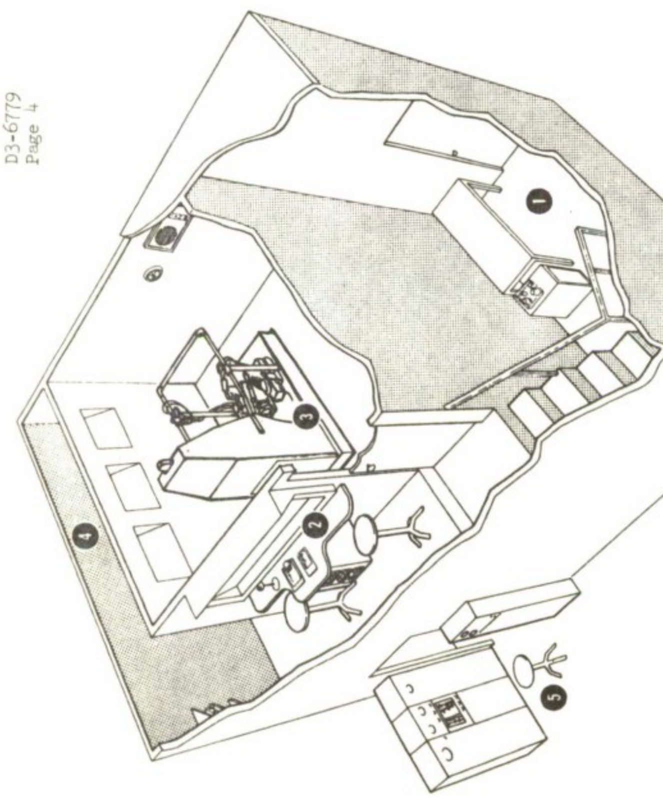
An illustration of the overall test station configuration used for the experiment is shown in Figure 2. Subject restraint was provided by specially designed and fabricated "boot tops" which fit over the subject's ankle, foot and shoe (leather soled, low quarter shoes were worn by the subjects) and could be set at any desired tension through the use of four cables attached to each restraint (Figure 3). Thirty pounds tension was determined in preliminary tests to provide the desired restraint capability and was used throughout this test.

The subject controls and display used in the program are shown in Figures 4 & 5. The controls consisted of pistol-type hand grips held in each hand. Each grip contained a three-position "trigger" switch at the index finger location and a thumb switch located on top (Figure 4). Depression of the right or left hand trigger switches, respectively, increased or decreased vibration amplitude. Moderate depression of a switch produced the slow rate of change and hard depression evoked the fast. In each case the appropriate indication appeared on the subject display. When neither switch was being activated, the amplitude remained constant and in the event of simultaneous depression, the "down" command automatically took precedance.



EXPERIMENTAL STATION CONFIGURATION

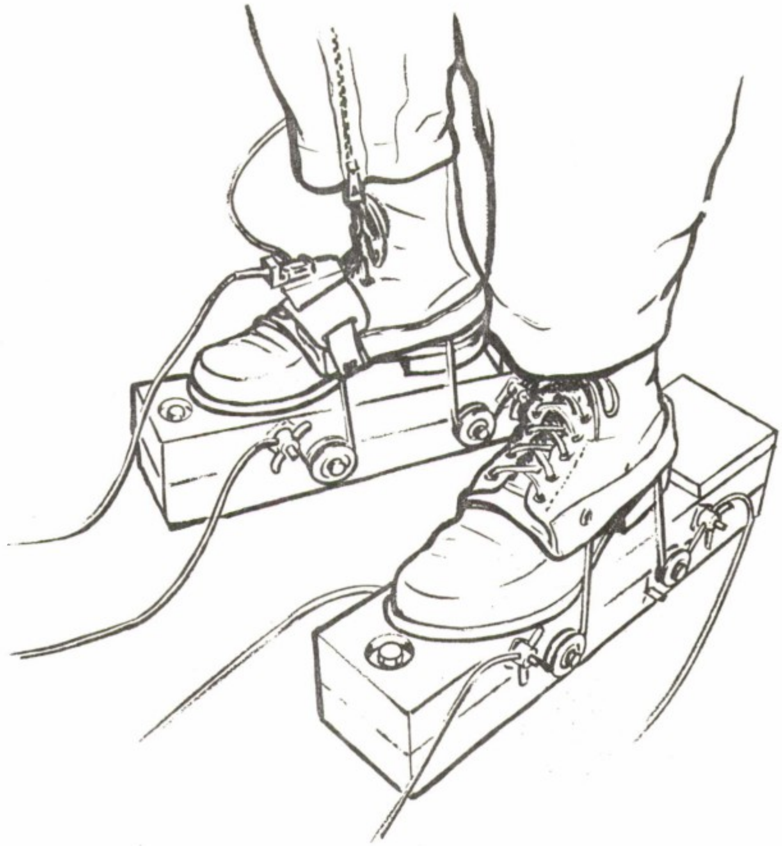
FIGURE 2



1. Entrance and Emergency Area
2. Experimental & Medical Monitoring Station (One-Way Observation Window)
3. Vibration Platform (Display Console & Safety Rail Mounted)
4. Observation Area (Three One-Way Viewing Windows)
5. Equipment Operator's Station (Signal Generation, Feed back, & Monitoring)

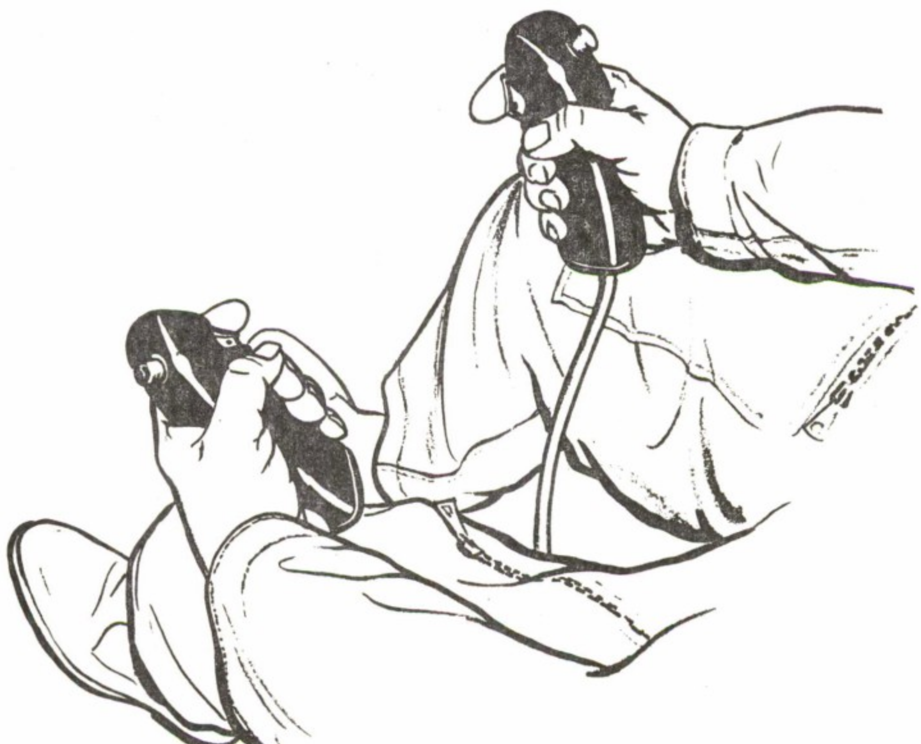
(Separate subject preparation and interview room not shown)

FIGURE 1. BOEING HUMAN VIBRATION FACILITY



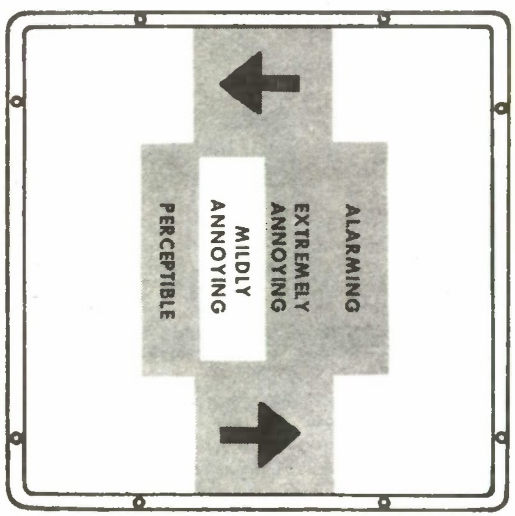
SUBJECT RESTRAINT SYSTEM

FIGURE 3



VIBRATION CONTROL HANDLES

FIGURE 4



SUBJECT DISPLAY CONSOLE

FIGURE 5

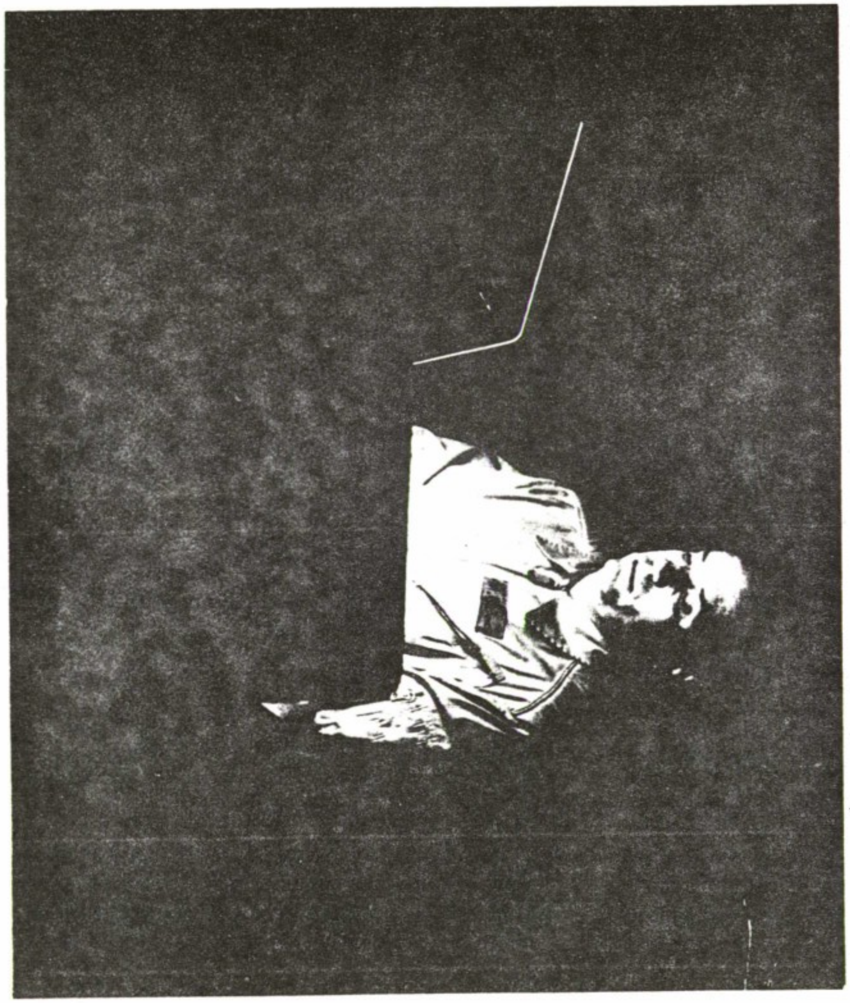
The right hand thumb switch was used by subjects to convey when an indicated subjective level was matched by the existing vibration, and served both to notify the experimenter of such a match and to automatically record, on an oscillograph, the acceleration being produced at each accelerometer location. The left thumb button was a cut-off switch and if pressed would immediately stop all vibration. Use of this switch was not required on any test during the reported program.

The display contained the four descriptive terms referencing the levels to be established which could be illuminated separately as required by the experiment, and "up" and "down" arrows which provided feedback indications to the subject concerning his control action in increasing or decreasing vibration amplitude. Amber illumination of either arrow indicated "slow" change (80 sec. from 0 to maximum amplitude) and white illumination referred to "fast" (40 sec. for total travel). The remaining portion of the display was lighted at all times during the test to illuminate the subject (Figure 6) so that he would be visible to the experimenter and physician monitoring the experimental session.

Monitoring of subject pulse and EKG, control of command indications given subjects, and communication control between subject, experimenter, and equipment engineer were accomplished at the experimenter-physician station shown in Figure 1. Equipment set-up and data recording were performed at the equipment operator's station.

Vibration Conditions

The vibration frequencies selected for use in this experiment were those utilized in the previous study in which the subjective reactions to vibration in the seated position were established, viz., 1, 1-1/2, 2, 3, 4, 5, 6, 8, 10, 12, 14, 16, 18, 20, 23, and 27 cps. Since limits of tolerance were not to be considered in the experiment, acceleration limits selected were below those previously established as tolerances by Ziegenruecker and Magid[4](1959). The limit utilized for each of the selected frequencies is listed in Table II.



SUBJECT ILLUMINATED BY PANEL

FIGURE 6

Table II

Table Acceleration Limits

Frequency (cps)	Maximum "G" possible
1	1.0
1-1/2	2.3
2	2.5
3	2.0
4, 5, 6, 8	1.5
10	1.9
12	2.25
14	2.6
16 - 27	3.0

Vibration Fidelity

Recordings of displacement and acceleration wave forms of the inputs to the subjects indicate excellent vibration fidelity. Displacement wave forms were nearly indistinguishable from superimposed sine waves at each frequency, with accleration wave forms near perfect at frequencies above 14 cps. From 1 through 5 cps acceleration waves showed generally less than 20% distortion, and from 5 through 14 cps in the range of 3% to 10%. Samples of acceleration waves with superimposed sine waves at representative frequencies of the study are shown in Appendix C.

Data Utilization

Data recorded during the experiment consisted primarily of vertical acceleration traces recorded on an oscillograph. Two channels of information from accelerometers mounted on the vibration platform were recorded at different scale factors to provide accurate readings regardless of the vibration level and for cross check purposes; an additional channel was recorded from an accelerometer mounted on top of the subject's foot for use in determination of the transmissibility of the restraint mechanism; and a fourth channel was taken from an accelerometer mounted on the subject's shoulder as an indication of body dynamics characteristics. Additional recordings of the table mounted accelerometers and continuous table position were recorded by electronic pen for backup and additional cross check.

Use of the data was entirely descriptive in nature. Because of a common tendency among subjects to reach the preset maximum table travel without the identification of higher subjective levels at some frequencies (with a resulting loss of data), medians were used as the central tendency measures. Post-test questionnaire data were utilized in study of the physiological effects of the vibration. Pre-test briefings were given to assure continued subject understanding of level definitions and test procedures.

Experimental Sequence and Test Procedure

Prior to the start of actual vibration testing, the subjects were provided with an orientation lecture about the program, copies of instructions, program schedules, and subjective vibration perception level definitions. (Subject instructions and level definitions are included in Appendix A). Also, answers to individual questions concerning the program were made at that time.

During the testing program, each subject encountered nine vibration sessions divided essentially into three units. The first session was used for subject familiarization to the facility and experimental procedures with resulting data not utilized. There followed two series of tests, each consisting of four sessions, during which two readings of each subjective level were recorded for each of the 16 selected frequencies. An individual schedule design may be seen in Table III. Frequency presentation and level establishment sequences are included in Appendix A.

TABLE III

INDIVIDUAL SUBJECT SCHEDULE

Session	Vibration Frequency and Level*			
	$F_{1,P}$**	$F_{2,P}$	$F_{3,P}$	$F_{4,P}$
Practice	L_1 L_2 L_3 L_4 L_1 L_2 L_3 L_4	L_1 L_2 L_3 L_4 L_1 L_2 L_3 L_4	L_1 L_2 L_3 L_4 L_1 L_2 L_3 L_4	L_1 L_2 L_3 L_4 L_1 L_2 L_3 L_4
	$F_{1,1}$	$F_{2,1}$	$F_{3,1}$	$F_{4,1}$
1	L_1 L_2 L_3 L_4 L_1 L_2 L_3 L_4	L_1 L_2 L_3 L_4 L_1 L_2 L_3 L_4	L_1 L_2 L_3 L_4 L_1 L_2 L_3 L_4	L_1 L_2 L_3 L_4 L_1 L_2 L_3 L_4
	$F_{5,1}$	$F_{6,1}$	$F_{7,1}$	$F_{8,1}$
2	L_1 L_2 L_3 L_4 L_1 L_2 L_3 L_4	L_1 L_2 L_3 L_4 L_1 L_2 L_3 L_4	L_1 L_2 L_3 L_4 L_1 L_2 L_3 L_4	L_1 L_2 L_3 L_4 L_1 L_2 L_3 L_4
...	...	...	...	...
	$F_{13,2}$	$F_{14,2}$	$F_{15,2}$	$F_{16,2}$
8	L_1 L_2 L_3 L_4 L_1 L_2 L_3 L_4	L_1 L_2 L_3 L_4 L_1 L_2 L_3 L_4	L_1 L_2 L_3 L_4 L_1 L_2 L_3 L_4	L_1 L_2 L_3 L_4 L_1 L_2 L_3 L_4

*Frequency sequence is randomized between subjects; level sequence, within subjects

**Frequency-test series designation; 1st frequency, practice test series; 1st frequency, 1st test series; 5th frequency, 1st test series; 13th frequency, 2nd test series; etc.

A given experimental session consisted of the following sequence of events.

1. The subject was given a pre-test physical examination including temperature, pulse and respiration rates, blood pressure readings on each arm in the prone, sitting and standing positions, and an aural heart examination.

2. Electrocardiogram electrodes and the shoulder accelerometer were attached to the subject (Figure 7).

3. The subject donned flight coveralls and took his position in the facility.

4. Restraining boots were placed on the subject and tension set at 30 lbs. (30 lbs. tension was selected on the basis of preliminary tests).

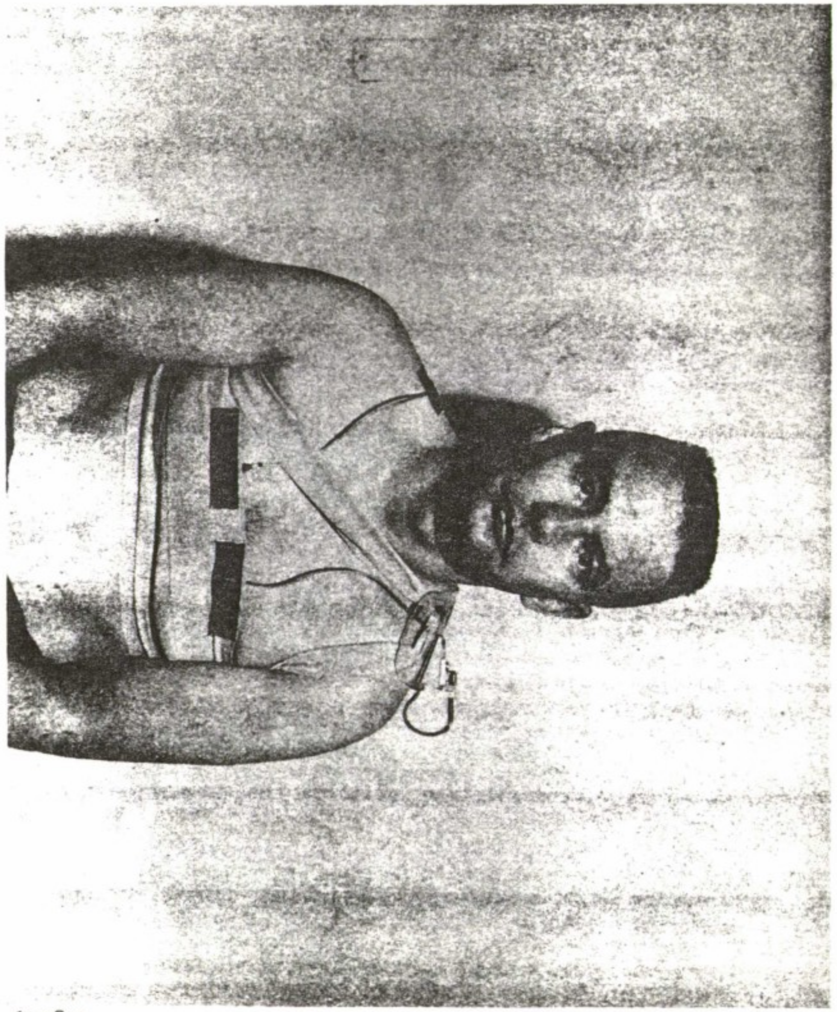
5. The foot accelerometer was positioned for the tests, and EKG and accelerometer leads were connected.

6. Daily instructions and level definitions (Appendix A) were read to the subject.

7. A group of four tests (four vibration frequencies) and debriefings was administered.

8. The subject was given a post-test physical (same items as pre-test), a composite debriefing, and was dismissed for the day.

A given single test sequence (step 7) involved the establishment of each of the four subjective vibration levels twice at a pre-selected frequency. The subject when positioned and ready for the test, was presented one of the levels through illumination of a portion of the display on which the desired label was inscribed and adjusted the vibration severity through his controls to match that level. When satisfied that the vibration being received was subjectively equal to the definition provided, he depressed the right hand event button, thereby automatically recording the acceleration level of the vibration, and cueing the experimenter to indicate the next level. Approximately 2 seconds were required for data recording and the process of indicating a new level, with no interruption or cessation of vibration required during the transition between levels.



SUBJECT WITH EKG ELECTRODES AND SHOULDER ACCELEROMETER MOUNTED FOR TESTS

FIGURE 7

Between tests, approximately 5 minutes was spent collecting comments concerning physiological and psychological responses to the vibration. Four tests were accomplished during each session and no subject encountered vibration on successive days.

A number of preliminary tests utilizing the present experimenter as test subject were conducted to help in the identification of controls necessary to the establishment of a valid set of subjective vibration reaction curves. Results of these tests showed visual reference to the non-vibrating environment, auditory cues produced by the vibrating mechanism, variations in restraining boot tension and subject position, and the capability of controlling the vibration received, all to have an effect on the amplitude of vibration perceived as being at a given level. Elimination of all light sources in the test room except those on the display, incorporation of a masking noise, the adjustable restraint devices, and the control handles were thus employed as the necessary controls for these intervening variables.

RESULTS AND DISCUSSION

Subjective Response Curves

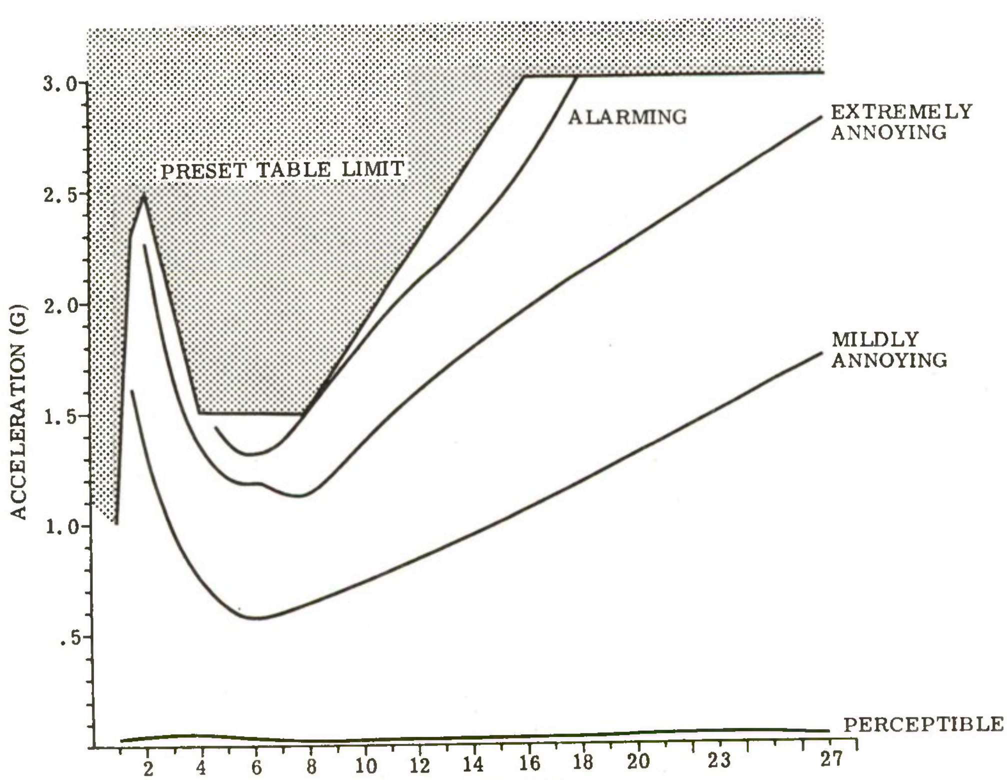
The subjective response curves established in the experiment may be seen in Figures 8 & 9. The curves represent smoothed plots of median acceleration values recorded from table mounted accelerometers; however, similar acceleration values taken from the accelerometer mounted on the subject's foot, as an indication of the fidelity of vibration transmissions, were nearly identical in all cases, with as much as 10% deviation extremely rare. Figure 8 shows the response curves on a linear scale; Figure 9 presents them in logarithmic relation to velocity, acceleration and displacement.

The response curves shown in Figure 8, have the characteristic shapes of subjective curves established in previous investigations of seated subjects (Chaney[2] 1964). The "perceptible" curve maintains a near constant acceleration value throughout the frequency range tested, and the remaining curves show decreased human tolerance in the 4 through 10 cps range, with a minimum acceleration required at 6 cps to evoke a given subjective response, increasing nearly linearly from that point upward through 27 cps.

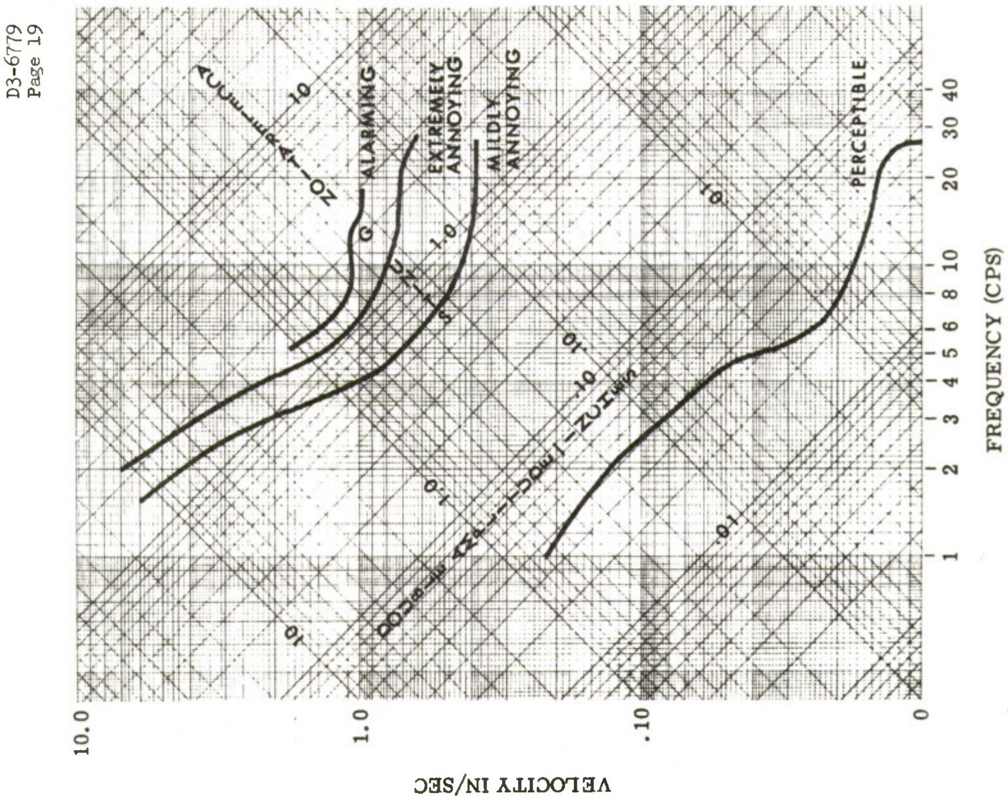
Comparisons of the curves with those established in the previous program in which the subjects were in the seated position, are shown in Figure 10. The "perceptible" curve of this study is, on the average, approximately .015 G less than that established with the subjects seated, the "mildly annoying" and "extremely annoying" levels are displaced slightly upward, and the "alarming" level is of approximately the same magnitude.

In Figures 11 through 14, medians, 20th and 80th percentiles for each of the subjective curves are shown for each of the two series of tests. In most cases the range between the 20th and 80th percentiles is reduced on the second series of tests from that obtained on the first. At the higher frequencies, a higher acceleration was generally accepted on the second encounter of a given frequency.

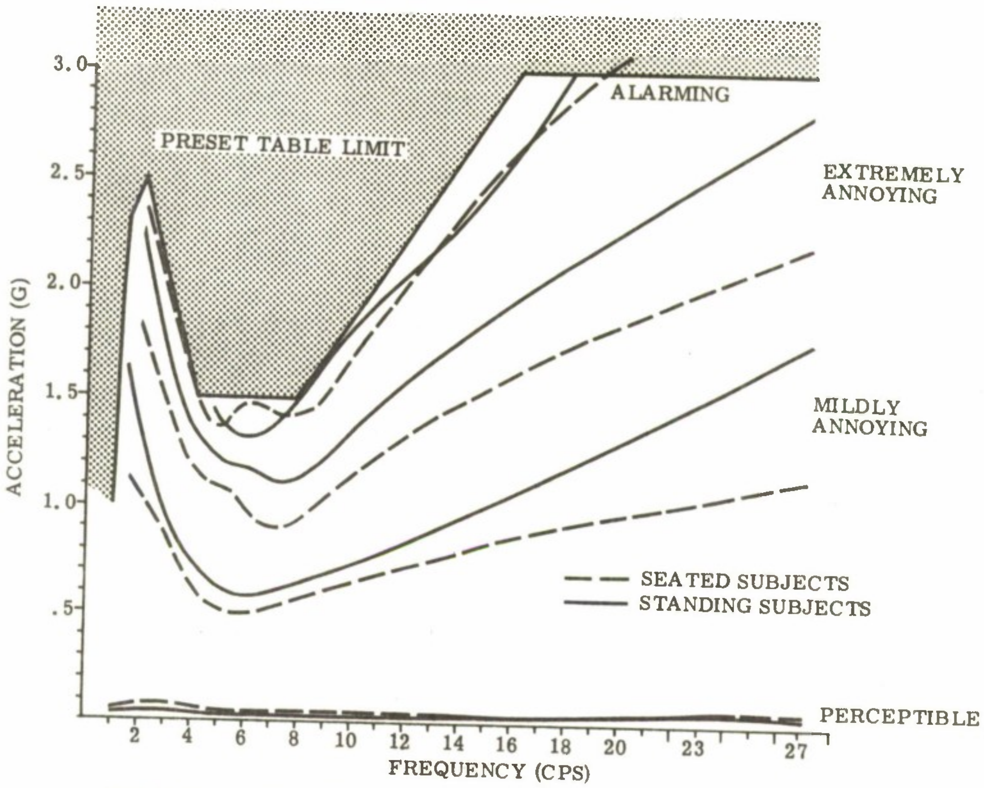
Acceleration received at the subject's shoulders during establishment of the "mildly annoying", "extremely annoying" and "alarming" levels is shown in Figure 15. Figure 16 shows the shoulder acceleration expressed as a percentage of table acceleration at each frequency with a $\pm$ one standard deviation band around the curve. Figure 17 shows this expression in comparison to similar ones derived by Dieckmann[3] (1957) for both seated and standing subjects.



SUBJECTIVE REACTION CURVES
FIGURE 8



SUBJECTIVE REACTION CURVES RELATED TO
VELOCITY ACCELERATION AND DISPLACEMENT
FIGURE 9



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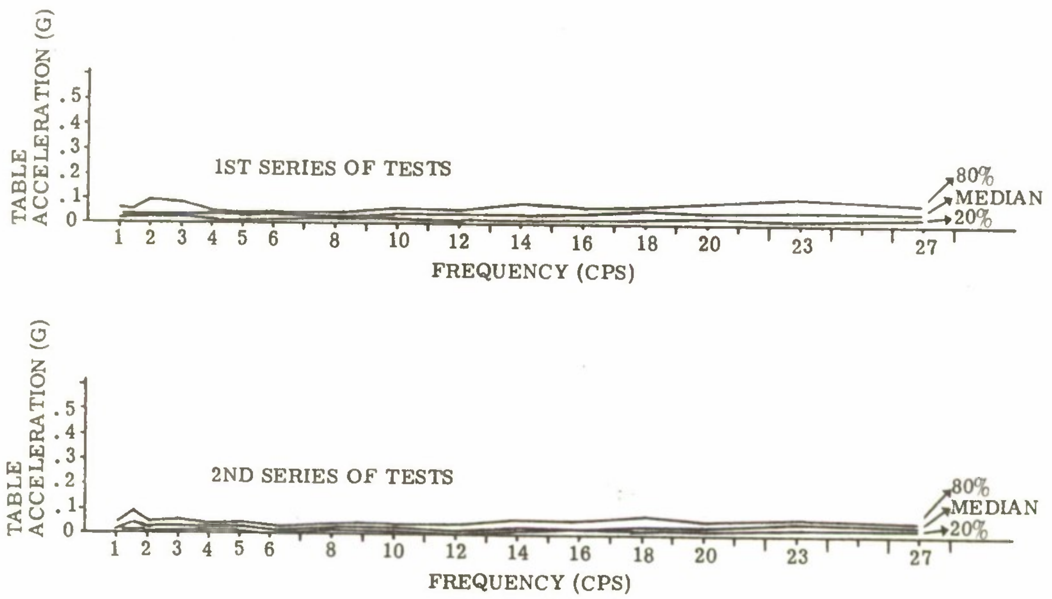
SUBJECTIVE REACTION CURVES - SEATED AND STANDING SUBJECTS

FIGURE 10



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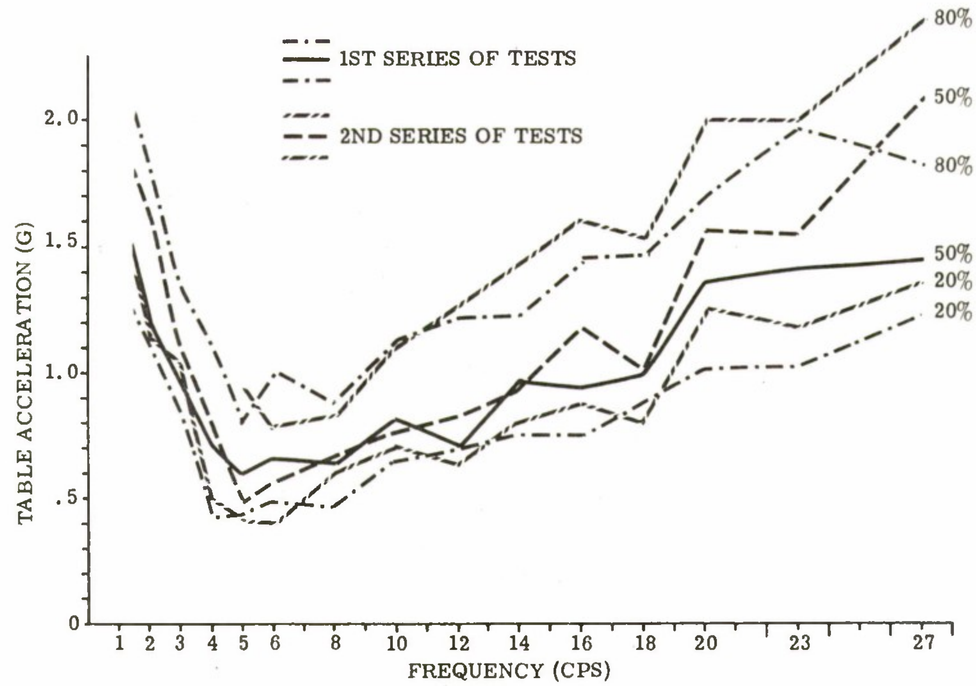
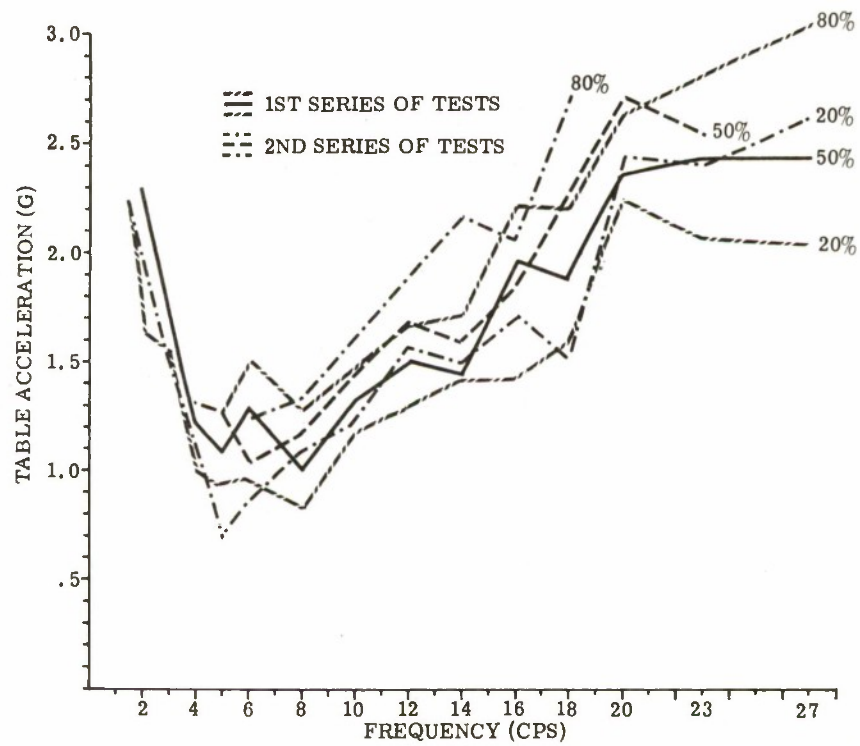
MEDIANS, 20TH AND 80TH PERCENTILES ESTABLISHED FOR PERCEPTIBLE LEVEL OF VIBRATION

FIGURE 11



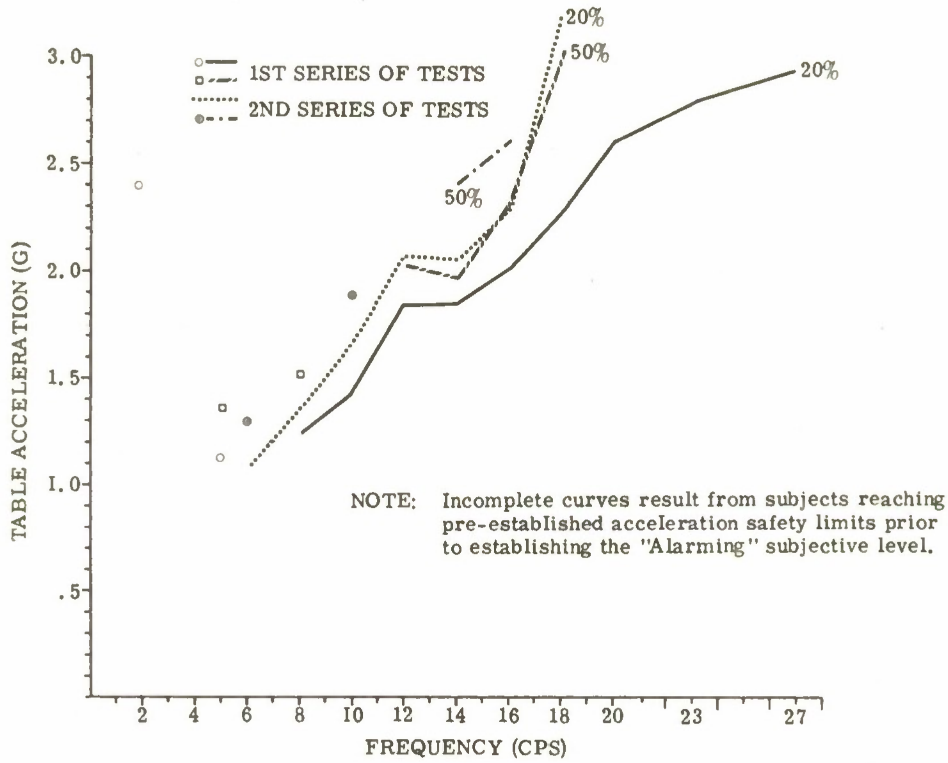
MEDIANS, 20TH AND 80TH PERCENTILES ESTABLISHED FOR MILDLY ANNOYING LEVEL OF VIBRATION

FIGURE 12



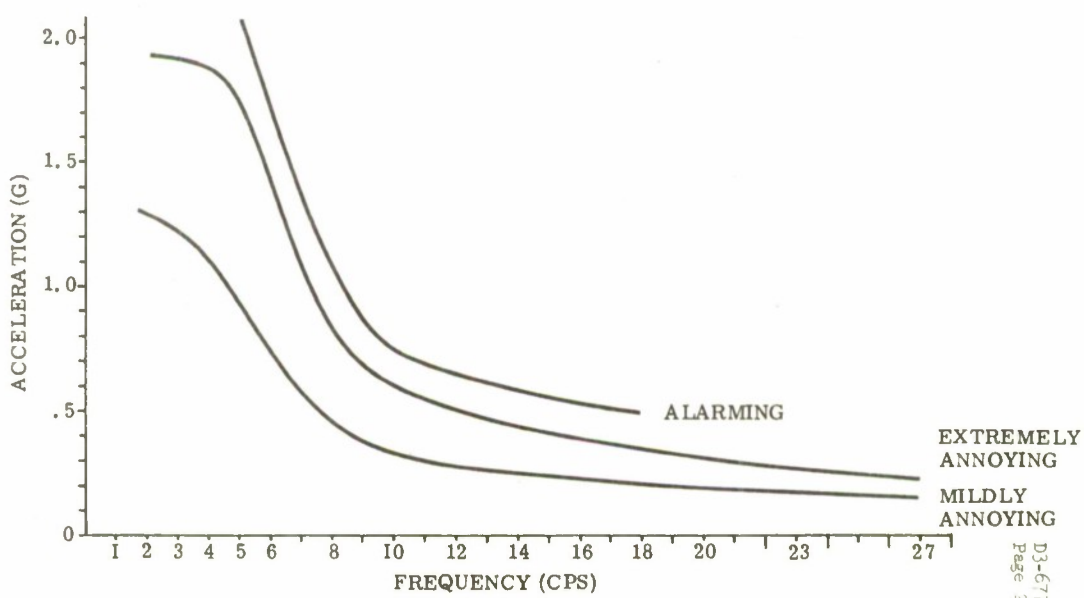
MEDIANS, 20TH AND 80TH PERCENTILES ESTABLISHED FOR EXTREMELY ANNOYING LEVEL OF VIBRATION

FIGURE 13



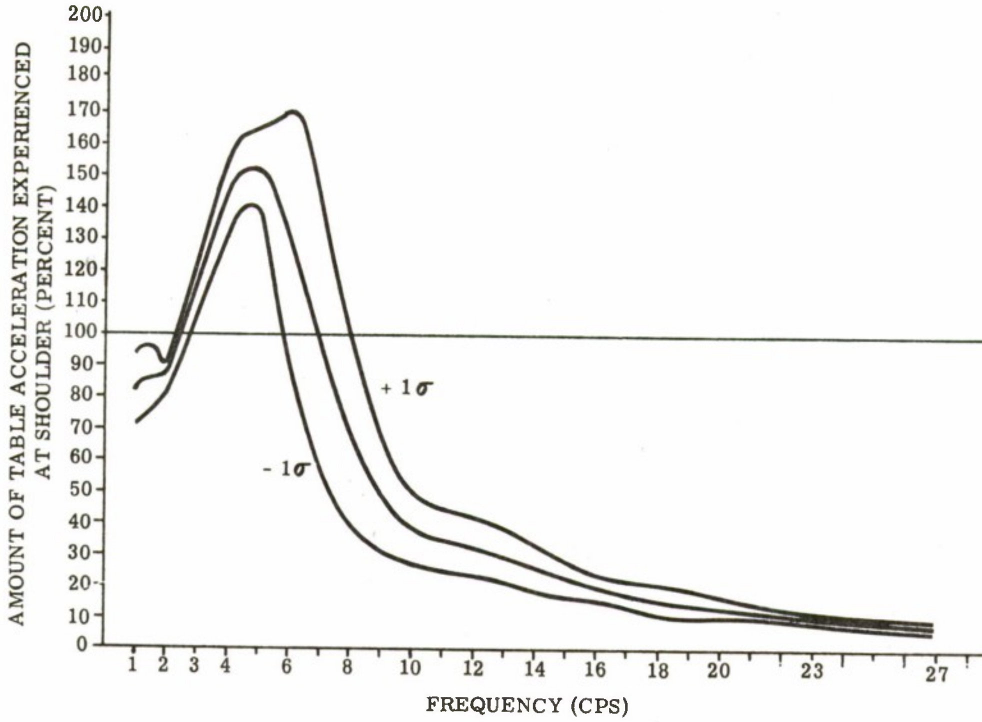
MEDIANS AND 20TH PERCENTILES ESTABLISHED FOR ALARMING LEVEL OF VIBRATION

FIGURE 14



ACCELERATION AT SHOULDER DURING ESTABLISHMENT OF MILDLY ANNOYING, EXTREMELY ANNOYING AND ALARMING SUBJECTIVE REACTION LEVELS (MEDIANS)

FIGURE 15



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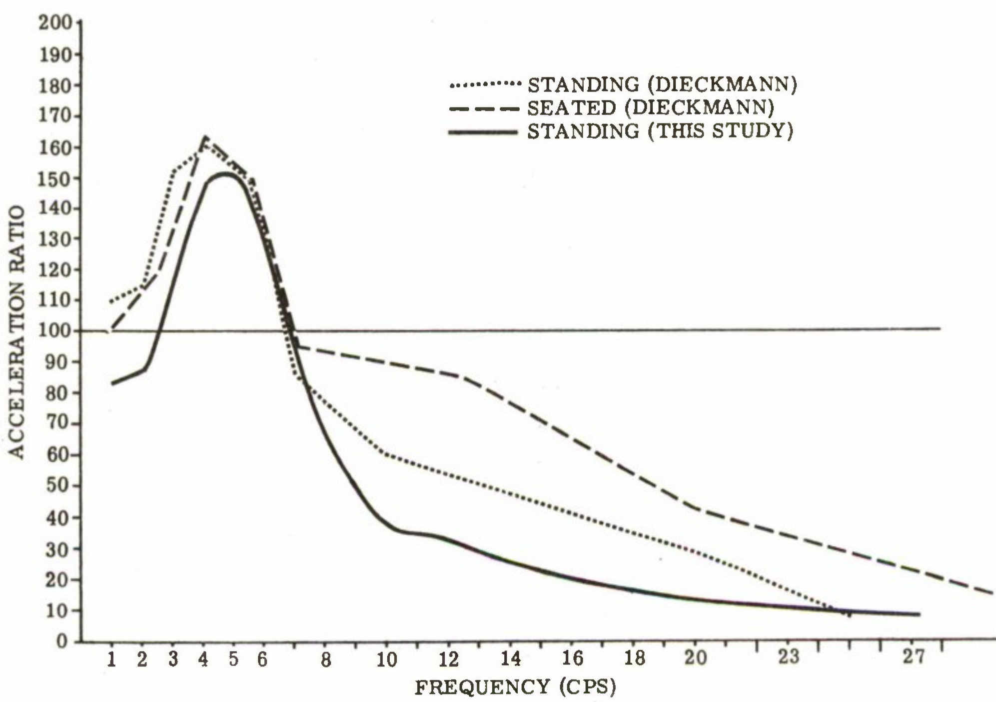
SHOULDER ACCELERATION EXPRESSED AS MEAN PERCENTAGE OF TABLE ACCELERATION

FIGURE 16



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SHOULDER ACCELERATION EXPRESSED AS A PERCENTAGE OF TABLE ACCELERATION

FIGURE 17

During the data collection phases of the study, the subjects who had participated in the previous experiment (establishing curves in the seated position), each stated they "felt" they were perceiving vibration at lower levels than in the seated tests; that considerably more vibration was required to reach a mildly annoying level; and that as vibration was increased beyond the mildly annoying level, the remaining levels were reached in relatively quick and positively accelerated succession. They further stated that the alarming level came on quite suddenly and that tolerance limits would have been reached with little additional increase. Much of this is supported by the data.

It was expected, as subjects reported and was the case, that the vibration would be perceived in these tests quicker than those of the previous tests, since at that time subjects were isolated from the vibration table by a 3/4 in. layer of hard felt at all body contact points. In contrast, subjects in this study were isolated only by leather soled low quarter shoes, which resulted in a "perceptible vibration" reduction of about .015 g.

What was not expected, is the increased acceleration required, particularly at higher frequencies, to evoke a "mildly annoying" or "extremely annoying" response, although further analysis in light of the available data would support such a prediction. Initially, the accelerations received by major body components of a subject in a vibration environment are the determiners of that subject's tolerance or response, while the vibration input to the subject influences his reaction only to the extent that it varies the acceleration actually received by these components. Plots of the shoulder acceleration, for example, result in smooth curves showing acceleration levels decreasing as frequency increases (Figure 15) rather than the reverse as is true with the vibration input. Also, Dieckmann[3] (1957) has shown that standing subjects "absorb" a larger percentage of vibration input (Figure 17), so that they actually experience less vibration in the upper portions of the body than in the seated position. Thus, with less vibration received in the areas of the body which apparently influence tolerance, the response would also be less.

A composite look at the curves established in the study only partially substantiate subject comments concerning what they felt had taken place with regard to the position of the curves relative to those of the previous study. The difference in acceleration values between the "perceptible" and "mildly annoying" curves is somewhat greater than that of the previous tests and the higher levels were reached in what could be considered postively accelerating succession. However, there is reason for doubt concerning the subject's ability to differentiate the noted difference in the lower curves, and certainly in their ability to recognize the smaller additions to acceleration required between successively higher levels. The response of the subjects to these higher levels would suggest increased apprehension on their part concerning their well being in the vibration environment while standing, and some increased concern is probably justified. Although subjects were restrained in both tests, and no subject mentioned fear or apprehension as part of either, the lap belt undeniably produced a deeper feeling of security than did the foot restraints of this study. If, for instance, a subject had lost consciousness during the respective programs, he would have had a greater chance of injury during the standing tests simply through the possibility of falling against the safety rail or to the table, and although any intent toward this degree of vibration was purposefully avoided, the possibility of such a happening exists in any situation. In addition, each of the subjects encountered some body sway (although not all were aware of it) and some had slight sensations of dizziness or balance difficulty during the higher levels at some frequencies. These conditions are at least a possible explanation of the smaller acceleration levels required in the upper portions of the body for an alarming subjective response, and through extrapolation to the reduced short time limit expected in the standing position.

Percentages of table input experienced by the subjects at the shoulder (Figure 16) is a function of frequency and is largely insensitive to amplitude or acceleration level. Subject body build and muscle tone apparently affected the frequency (around 6 to 8 cps) at which the body no longer amplified input acceleration and began absorbing input energy; but beyond this point all subjects reacted in similar manner. This is shown clearly by the one standard deviation range around the mean acceleration ratio shown in Figure 16. Also, although the scale factor of the shoulder accelerometer was such that no readings could be

obtained at the "perceptible" vibration level, the percentages of table accelerations received at the shoulder throughout the remaining levels at a given frequency displayed exceptional unanimity, varying only a few percentage points throughout the acceleration range tested.

As in the seated vibration response study, results of the second series of tests varied somewhat from those of the first (Figures 11, 12, 13, & 14). An accommodation to the vibration was demonstrated with somewhat higher acceleration values experienced by subjects during the second test series at the higher frequencies; and subjects apparently achieved a better understanding of level definitions resulting in decreased ranges of scores during the second encounter of the test conditions.

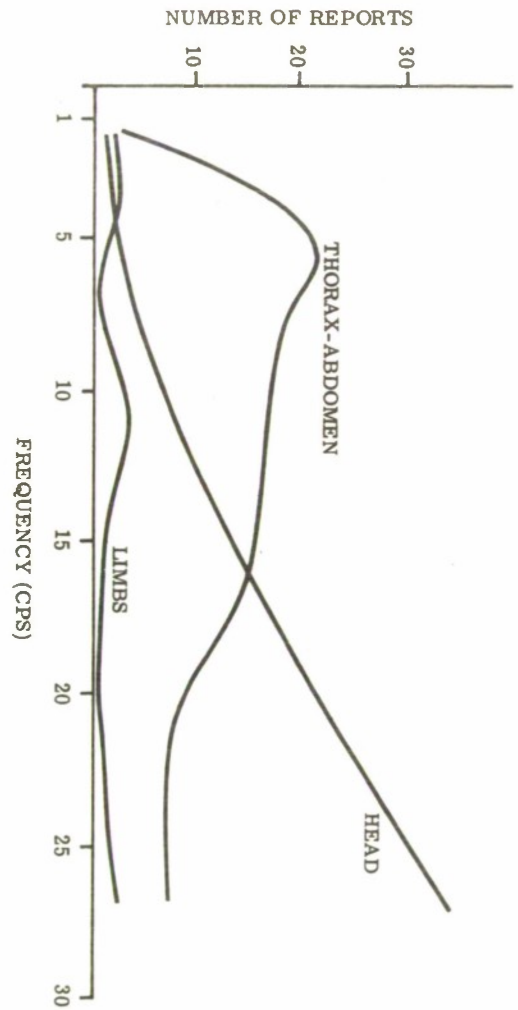
Physiological Effects

Between vibration test frequencies and following each session, comments concerning the vibration and its effect on the subject were solicited and recorded. No check list type data sheet was used and subjects were allowed to make whatever comments they felt appropriate, including the opinion that no significant effects were present. Reports collected during the program are shown in Table 4. In general, the pattern of reported physiological effects encountered by the subjects is like that reported in previous studies in which the subjects were seated. At the lower frequencies of the study, effects were primarily concentrated in the thoracic-abdominal areas, moving upward in the body as frequency increased until at 27 cps (the highest frequency tested), head effects were predominant. This relationship between the various body areas is shown in Figure 18. In looking at the curves it should be remembered that free discussion was permitted and effects which may have been present in certain areas of the body were probably obscured by those which were most annoying or obvious. Such an effect would account for the reduction in the number of reports made concerning the thoracic-abdominal regions when head effects are predominant, and reduction in the reports of the limbs as each of the other reported areas were being emphasized. The main deviation from reports of previous studies appears to be directly related to subject position. Body sway and balance difficulties were present at the higher levels of some frequencies, and a slight sensation of dizziness was associated with these in the upper frequency range. On one occasion, a subject actually felt the need to reduce vibration because of a feeling of light headedness.

TABLE IV
PHYSIOLOGICAL REPORTS MADE DURING PROGRAM*

	FREQUENCY (CPS)															
	1	1-1/2	2	3	4	5	6	8	10	12	14	16	18	20	23	27
HEAD AND THROAT																
Head Out of Phase					1	2										
Visual																
Blurring										2	3	5	3	8	1	6
Perception of Color											1	1	2			2
Nose Itch								1	1				1	1		1
Ear Itch								1		1	1			1	2	
Teeth Chatter										1			2	1	2	3
Skin "Crawl" or Shake									5	3	5	3	1	4	3	4
Valsalva									1		1	1	2	4	2	2
Dyspnea		1				2	3	1	3	1		3	4	4	1	8
Eructation		1		1	1				1							
TRUNK																
Skin Irritation				1		2				1	2	2	2	3	3	4
Shoulder Shake and/or Pain			2		8	8	4	1								
Chest Tightness and/or Pain			1	1	1	5	4	3	3	1						
Side Tightness and/or Pain					2	1	3	2	3	1	2	1	1			
Back Tightness and/or Pain			1	1	1		4	3	7	2	1	1	1	1		
Abdomen Shake and/or Pain		3	4	3	4	3	5	6	3	3	1					
Buttock Shake			3	2	4	2	2	1								
Internal Organ Shake					1	1		1	1							
Genital Shake and/or Pain				1			1			1	1	1	1			
Gas Pains				1				1		1						
Bladder Pressure				1			1		1	5	8	5	5	3	2	2
Bowel Pressure									1		4		2	1	2	2
APPENDAGES																
Arm Flailing					2		1									
Tendency to Flex Legs			2	2	1			1								
Skin Irritation				1					3	3		1		2		4
GENERAL																
Slight Sensation of Dizziness						1	1		1	2			2	1	1	1
Body Sway or Balance Difficulty		1	1	2		1		1			3		2	1		
Sweating		1							1			1				
Warm Sensation						1									1	1
Cool Sensation										1						
Sensation of Nausea	1	1		1												

*Numerals indicate the number of individual reports



RELATIONSHIP BETWEEN BODY AREAS AFFECTED BY VIBRATION

FIGURE 18

As an additional measure of the physiological effects of vibration, blood pressure readings were taken on each arm of the subjects in reclining, sitting, and standing positions both before and following each vibration session. Comments made by Dr. Salomon (the attending physician) concerning these data follow.

"Preliminary review of these statistics indicate that throughout the session the five subjects showed an average decrease four to eight points in their post vibration blood pressure. Three of them, however, after one session showed a slight increase in their post vibration blood pressure.

It would appear that, if the above indications are confirmed by further statistical analyses, there apparently develops post vibration a peripheral and/or viscèral vaso-dilation. Same would probably be related to a sympathetic-parasympathetic interrelationship and to a fatigue syndrome of the musculature tone of the vessel walls, especially of the venous system.

Further postulation on such a hypothesis leads to a strong potentiality that such a reaction, especially when associated with the known respiratory arrhythmia that occurs frequently in individuals when they are in tense situations, would indicate a possibility for the development of hypoxia or decreased awareness and/or muscular control of pilots who are in turbulent or low level profiles for varying periods of time. Such a hypothesis could explain to some degree the occasional unusual sensitivity to positive G forces shown by some individuals.

Further studies and statistical analyses, of course, are indicated."

SUMMARY AND RECOMMENDATIONS

This research program was conducted to provide information concerning the reaction of the restrained standing subject to whole-body vertical vibration, utilizing control conditions similar to those under which currently available data were obtained for subjects in the seated position (Chaney,[2] 1964). Four subjective vibration reaction levels; viz., "perceptible", "mildly annoying", "extremely annoying", and "alarming" were established in the range of 1 through 27 cycles per second.

The "mildly annoying" and "extremely annoying" levels established were at higher acceleration input values than their counterparts of the seated studies, with only minor variations in the "perceptible" and "alarming" curves under the two conditions. Differences in body absorption characteristics of the standing and seated subject are offered as a possible explanation of the noted differences in the curves. Except for an increased incidence of body sway and balance difficulty, physiological effects appear to be very similar to those encountered in the seated position.

It was not expected, prior to the experiment, that standing subjects would require as much vibration input to elicit a given response as had been found necessary in the seated position. The fact that in some cases more vibration input was actually required, even with subjects not permitted to flex the legs during testing, may require a revision in thinking concerning man's capabilities in a vibration environment. Since in normal operational situations, vibration is seldom of a sinusoidal nature, and with the known absorption characteristics of the flexed leg to compensate for periods of extreme vibrations in random conditions, a standing operator may have advantages in situations for which he is not generally considered. Additional studies are needed to establish whether increased "tolerance" in the standing position will also produce increased performance on an operational task, and if so, interaction effects of fatigue, restraint method, etc. Still other studies would be required to determine which types of jobs and environments could most efficiently utilize the operator in this position.

APPENDIX A

INSTRUCTIONS TO SUBJECTS AND TESTING SEQUENCES

SUBJECT INSTRUCTIONS

In your participation as a subject of the vibration program, you will be aiding us in identifying some of the descriptive aspects of the sensation of vibration. These descriptions will prove valuable to the design engineer and those evaluating performance under vibratory environments. Vibration intensities which you will be asked to identify at various frequencies are defined on the accompanying sheet.

It should be noted that the labels provided are meant only to serve as indicators of the definitions to which you will fit the various vibration intensities. The description given may not fit your own personal interpretation of the labels. In this case, we are asking you, for the purpose of this test, to make sure you understand the given definition and work toward it disregarding the label.

You will notice that in each definition the word "you" appears, and with good reason. What we are looking for is your interpretation of the defined intensities, not what you think would be true for others. Also, for this reason we request that you not discuss among yourselves any of the levels or conditions of vibration. Individual reactions are required if we are to accomplish our objectives.

During the test sequences you will be presented, by means of a visual display, a label referencing the definition to which you are to adjust the vibration intensity. You will have control of the facility and will be able to increase, decrease, or maintain any vibration intensity within facility limits. In each test each identification will be made twice, but order of their appearance will vary from test to test. Also, since the vibration mechanism is limited for safety and equipment reasons, some frequencies may not contain for you the intensity required for one or more of the definitions. In these instances, where you request through your controls, a level beyond equipment capability, notification to that effect will be made by the experimenter and a new definition will be requested. You will then proceed with the new adjustment.

Control of the facility is accomplished by means of two pistol type hand grips held in either hand. Each has a two position "trigger" switch for the index finger and a thumb actuated push button located on top. The trigger switch controls upward and downward table movement respectively with the right and left hand. Hard

depression of the switch accelerates the rate of change in each case. The right hand thumb switch is used to indicate when you have adjusted the vibration to the point which in your opinion matches the definition provided and will be used several times during each test. The left one shuts down the facility and is provided for use only if you feel for some reason you must immediately stop vibration.

On the right hand side of the display panel is an arrow pointing up. This will be illuminated an amber color when you actuate the right hand switch to increase vibration intensity. When the switch is pressed down hard, to use the higher rate of change, the arrow illumination will be white. The down-pointing arrow on the left hand side of the panel provides the same indications for the left hand control while decreasing vibration intensity.

In making the vibration adjustments, we are interested in those judgements or feelings only with regard to vibration as a sensation and not with respect to your experiencing this as an environment in which to do something else. Thus, do not react to the vibration facility as a simulator and judge its characteristics as if you were performing some kind of task or operation. Consider the vibration only as a stimulus in its own right, keeping your attention centered on the lighted panel. Do not try to evaluate or compare levels by relating your movement to any fixed object in the area. We want your unbiased opinion as to the effect you feel from the vibration. If it helps your concentration to close your eyes, this is permissible. If, at any time, you cannot find the defined vibration sensation, please notify the experimenter and he will proceed with the next step.

Daily Subject Instructions

To assure standardization in our experimental techniques and therefore a minimum of differences in your results, several items of importance to the test need to be reviewed prior to each test session. We realize you have heard and remember most if not all of the items from previous tests, but we ask your indulgence in the review.

Most important, of course, is an understanding of the four levels of vibration which you identify at each frequency and we have decided to review these at the start of each test period.

Definitions of Subjective Vibration Levels

1. Perceptible — This is the lowest intensity of vibration which can be felt. Going up the scale, this is the point at which you first become aware that you are receiving vibration. Going down the scale, this is the point at which all sense of vibration disappears.

2. Mildly annoying — This is the lowest intensity of vibration at which any unpleasant or annoying effects are felt. Below this point you are aware of the vibration, but it arouses no undesirable feelings. Below this point there may even be some pleasant aspects.

3. Extremely annoying — This is the lowest intensity of vibration at which unpleasant or annoying effecta become disturbing to a major degree and cannot be ignored. You would prefer not to continue at this intensity without good reason.

4. Alarming — This is the intensity of vibration at which you begin to experience concern for your physical well-being. There is not necessarily any pain present, but there is a distinct desire to reduce the vibration severity. You have misgivings about staying at this level any longer or going beyond it.

Also, we ask that you stand erect and not try to reduce the vibration inputs through bending of the legs, etc. You may, of course, reduce the effects of vibration received through techniques of your own . choosing, but we ask that you don't attempt to modify what is received.*

Too, we have found in previous tests that using the fast rates of vibration change (hard depression of the appropriate switch), has worked most satisfactorily when going between levels. How you choose to approach and decide upon the exact level of vibration which matches the definition provided is your choice, but we ask that you use the fast rates between levels where large changes are required. This is most important in reducing vibration after making selections at the higher levels.

In making your selections, please hold down the event button until a new level appears on your display. This provides us the 1 or 2 seconds required to collect the necessary data.

As for communications, none are required on your part. We will notify you when the table is coming up prior to each vibration and when the test is started and over. No others are scheduled. However, your microphone is "hot" and you may make comments concerning the vibration or ask questions at any point during the test. Also, we have limits set on the table at each frequency and it is possible that you may reach these limits without identifying one or more of the defined levels. In such cases, we will notify you of "maximum amplitude" and provide you with a new level. It is also possible that you can not find a vibration in some case which you feel matches the definition provided. In this event if you will notify us of the fact we will again proceed to the next level.

Are there any questions?

* Tensing of abdominal and back muscles was used by all subjects to reduce internal organ and "flab" shake. It was considered a normal response to the vibration and was permitted.

TABLE V

FREQUENCY SEQUENCE SCHEDULE

Sequence I Sessions	Frequency (cps)	II Sessions	III Sessions	Frequency (cps)	IV Sessions
1	18 1 20 14	8	1	10 3 27 1	8
2	3 27 12 2	7	2	14 20 23 2	7
3	23 5 1.5 8	6	3	5 16 6 1.5	6
4	6 10 4 16	5	4	4 12 8 18	5
5	5 14 20 6	4	5	4 23 6 1	4
6	1 4 23 8	3	6	5 14 8 27	3
7	1.5 12 18 2	2	7	16 2 1.5 18	2
8	27 3 10 16	1	8	10 20 3 12	1
Subjects					
1, 5		2	3		4

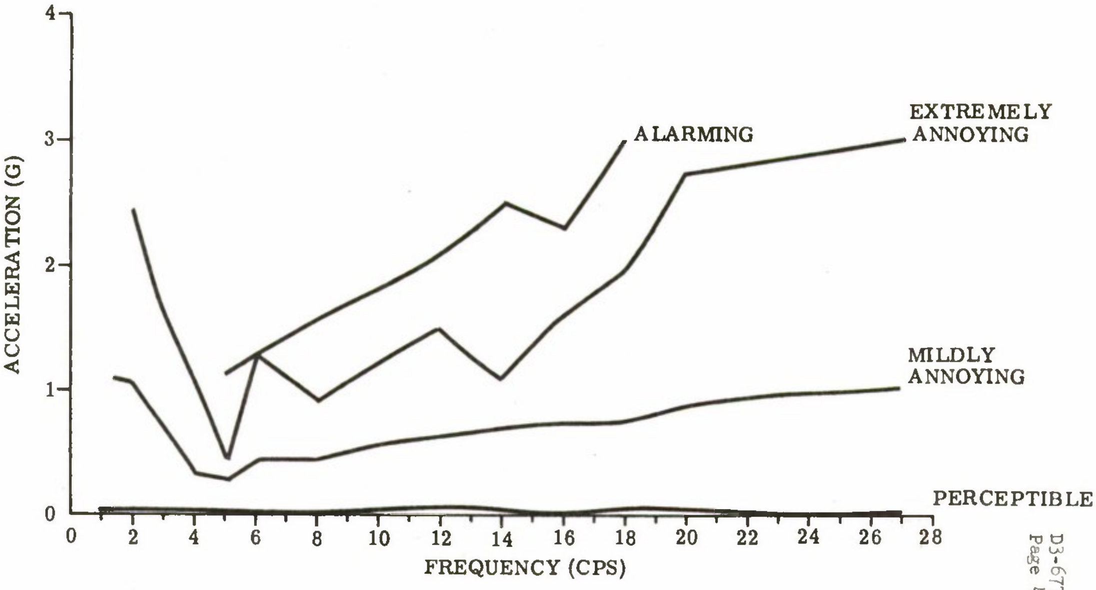
TABLE VI

LEVEL ESTABLISHMENT SEQUENCES

A	E
1, 3, 1, 2, 4, 3, 4, 2	2, 4, 3, 4, 2, 1, 3, 1
B	F
2, 4, 3, 1, 4, 2, 3, 1	1, 3, 2, 4, 1, 3, 4, 2
C	G
3, 1, 2, 4, 3, 2, 1, 4	4, 1, 2, 3, 4, 2, 1, 3
D	H
4, 2, 1, 3, 1, 2, 4, 3	3, 4, 2, 1, 3, 1, 2, 4

Presentation Order -- All Subjects

Session	Sequence	Session	Sequence
1	A B C D	5	B D A C
2	E F G H	6	F H E G
3	D C B A	7	C A D B
4	H G F E	8	G E H F

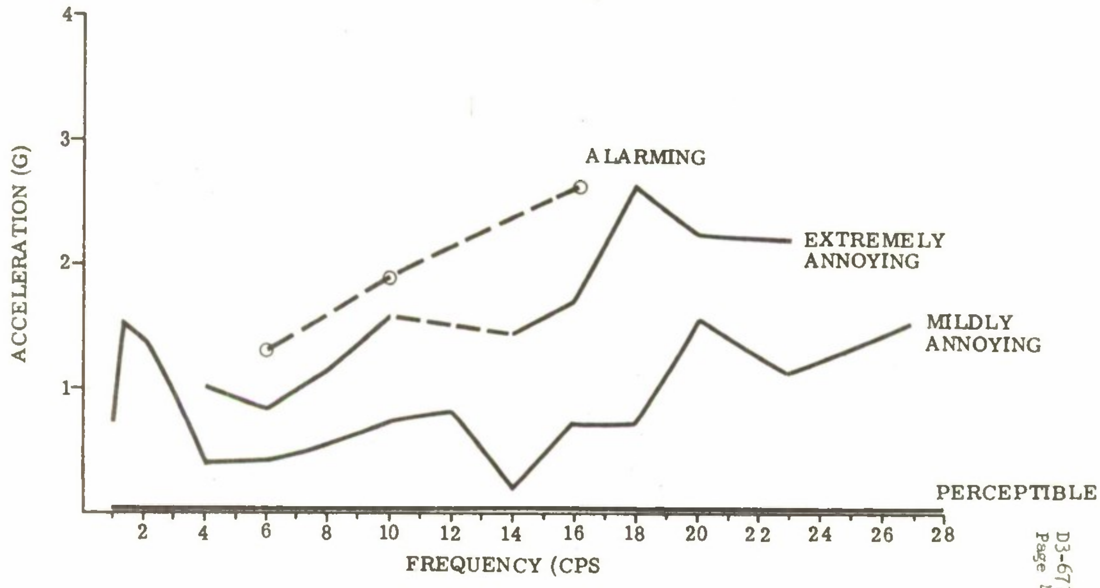


SUBJECT NO. 1, 1ST SERIES OF TESTS

FIGURE 19A

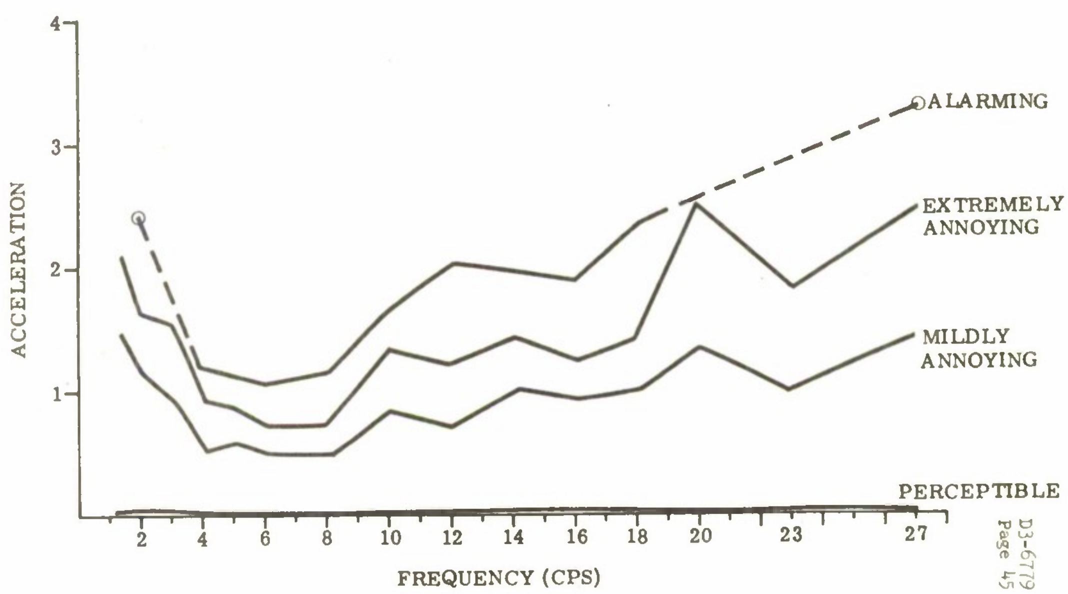
APPENDIX B

INDIVIDUAL SUBJECT RESPONSE CURVES



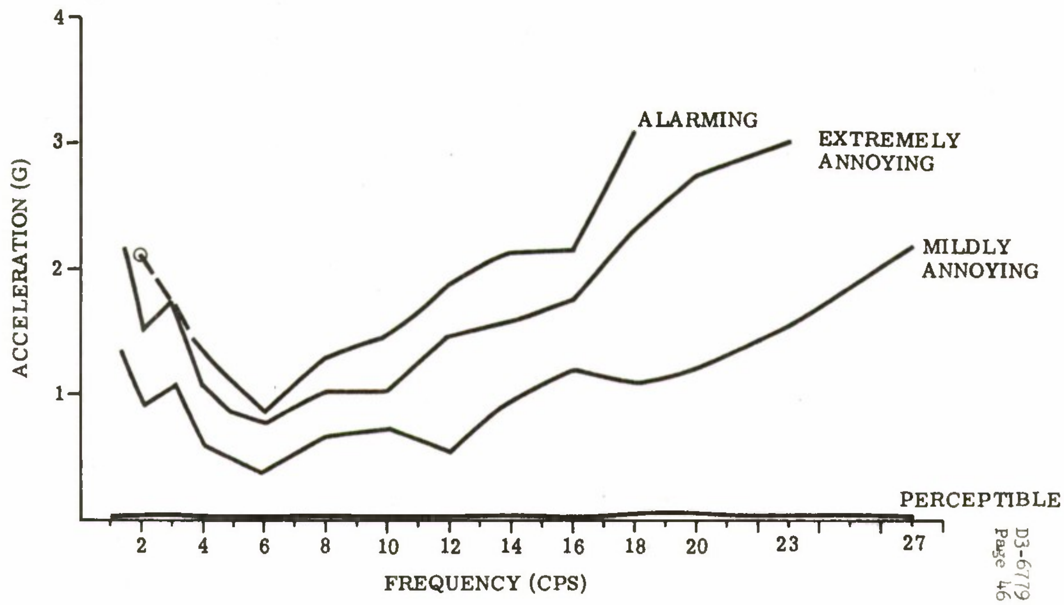
SUBJECT NO. 1, 2ND SERIES OF TESTS

FIGURE 19B



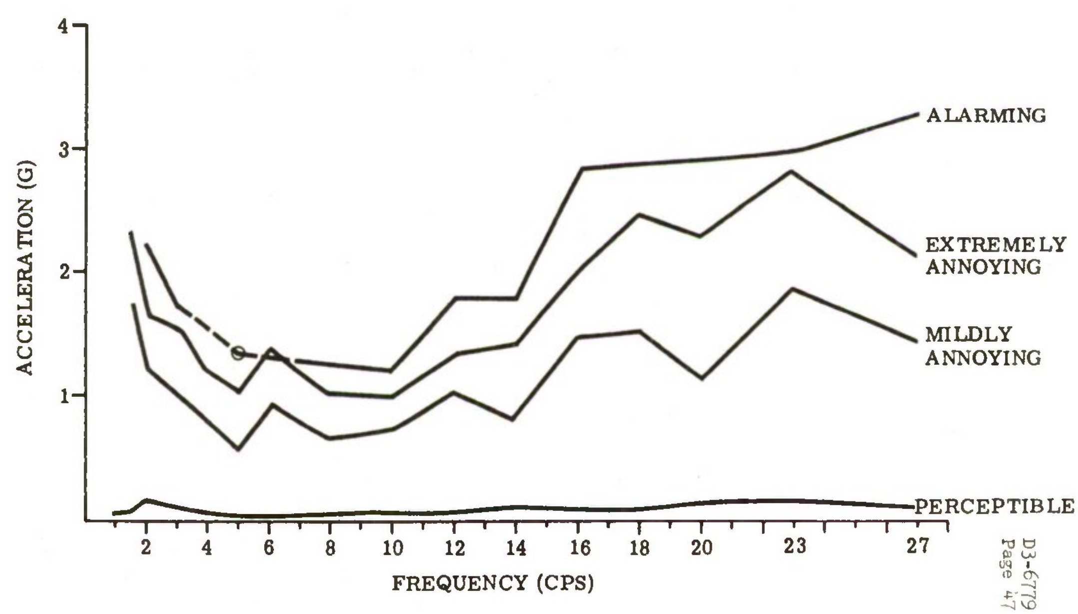
SUBJECT NO. 2, 1ST SERIES OF TESTS

FIGURE 20A



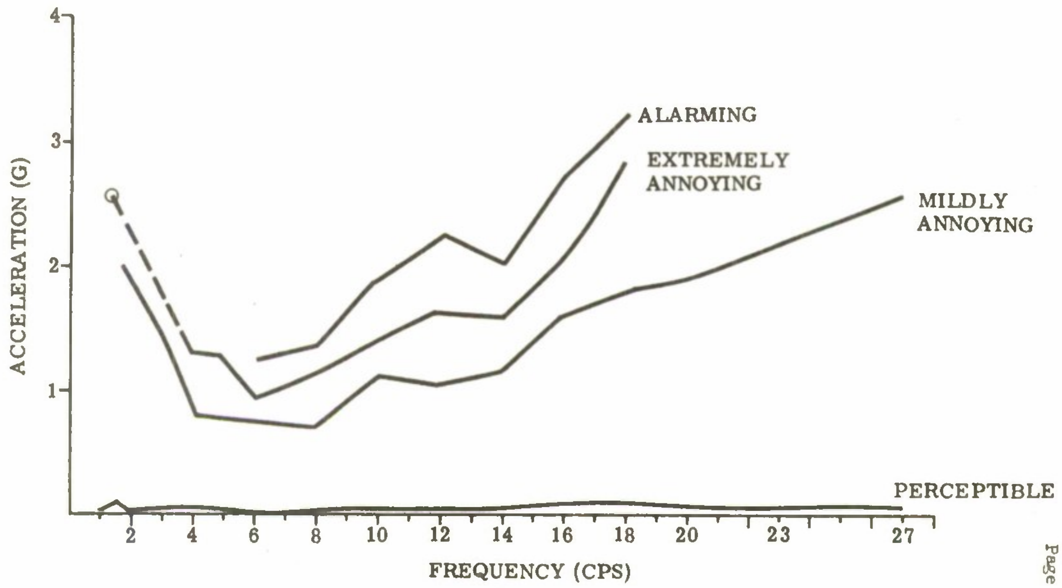
SUBJECT NO. 2, 2ND SERIES OF TESTS

FIGURE 20B



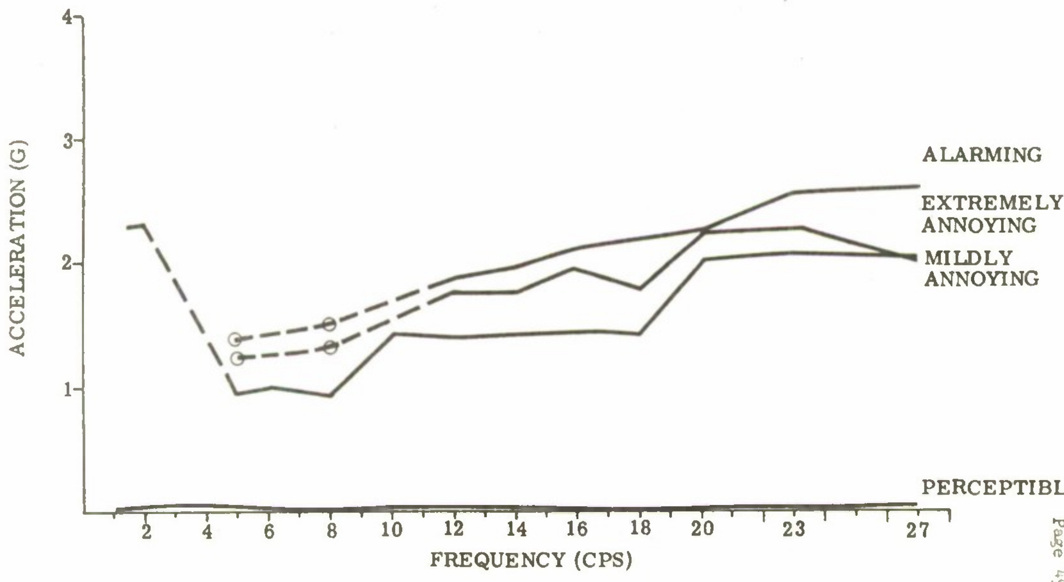
SUBJECT NO. 3, 1ST SERIES OF TESTS

FIGURE 21A



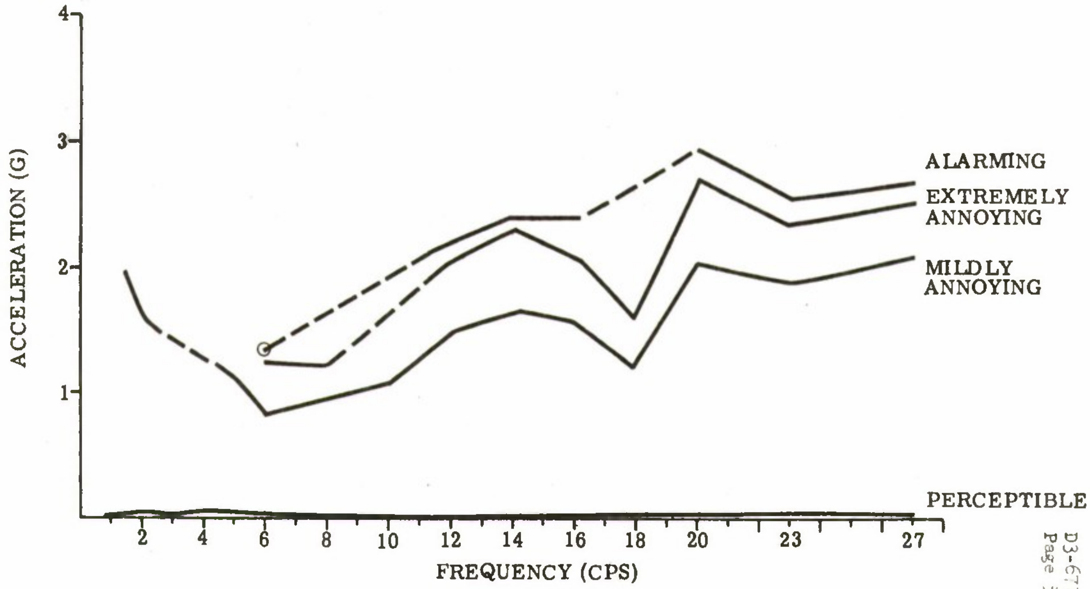
SUBJECT NO. 3, 2ND SERIES OF TESTS

FIGURE 21B



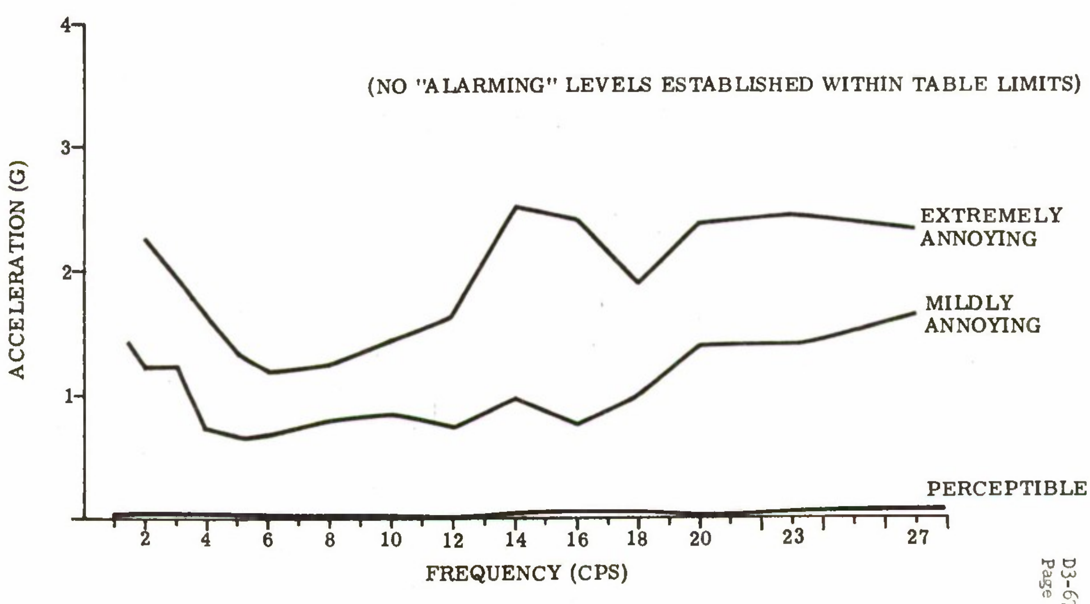
SUBJECT NO. 4, 1ST SERIES OF TESTS

FIGURE 22A



SUBJECT NO. 4, 2ND SERIES OF TESTS

FIGURE 22B

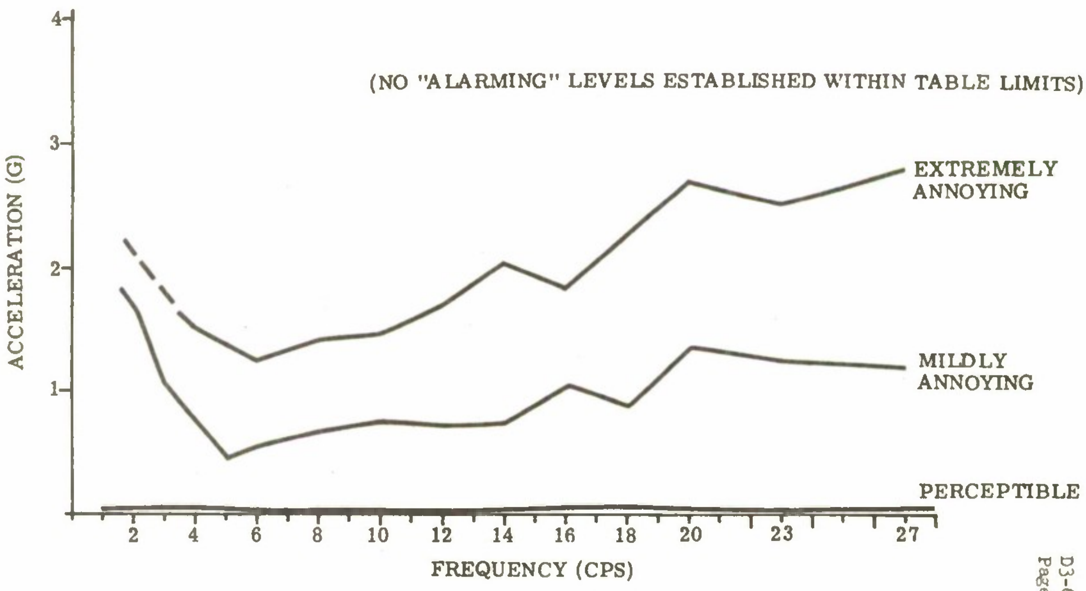


SUBJECT NO. 5, 1ST SERIES OF TESTS

FIGURE 23A

APPENDIX C

SAMPLE ACCELERATION WAVE FORMS



SUBJECT NO. 5, 2ND SERIES OF TESTS

FIGURE 23B

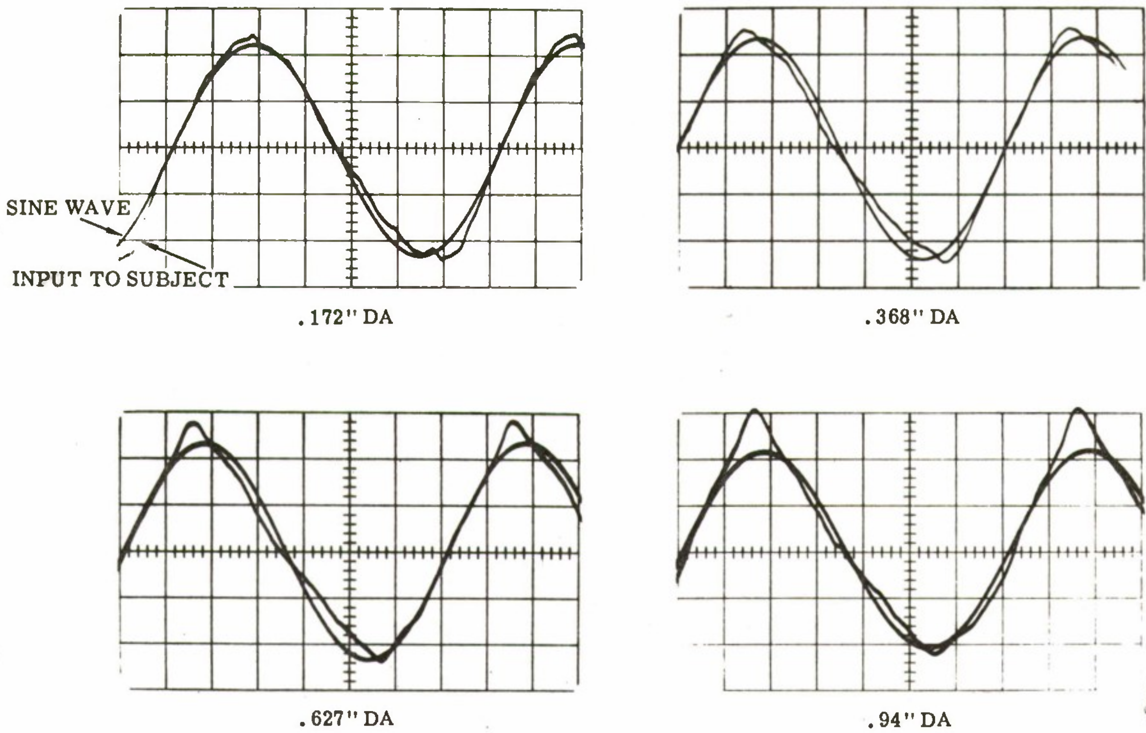


FIGURE 24 5 CPS ACCELERATION CURVE-SINE WAVE COMPARISONS

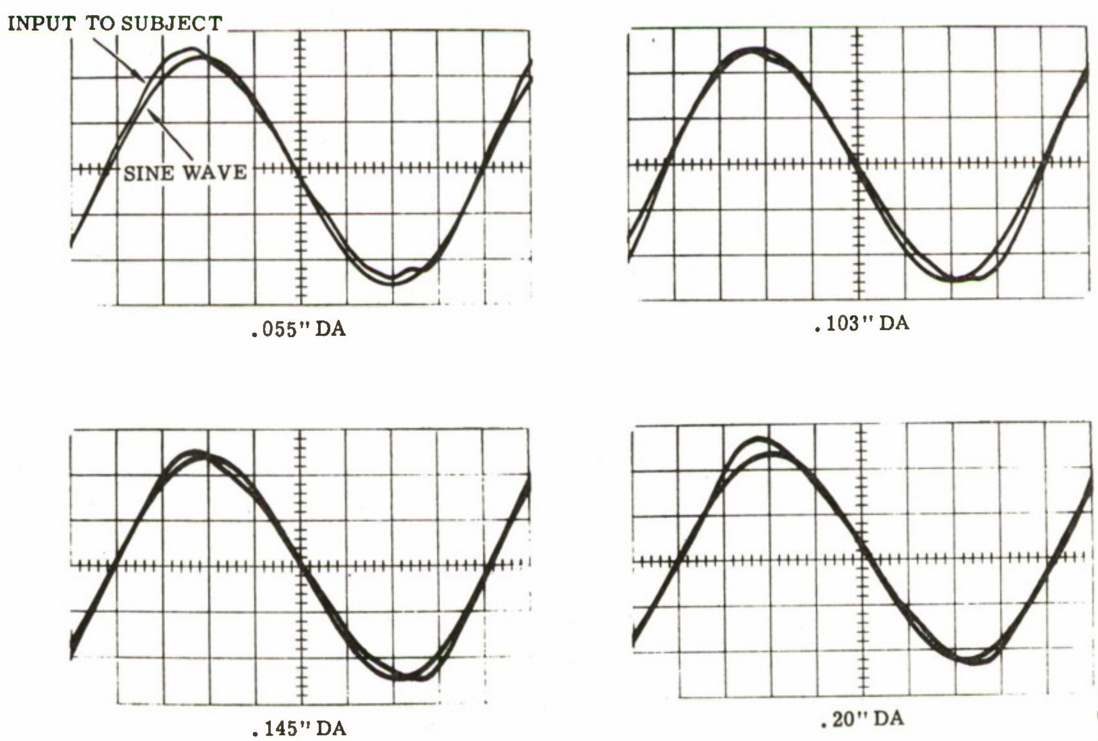


FIGURE 25 10 CPS ACCELERATION CURVE-SINE WAVE COMPARISONS

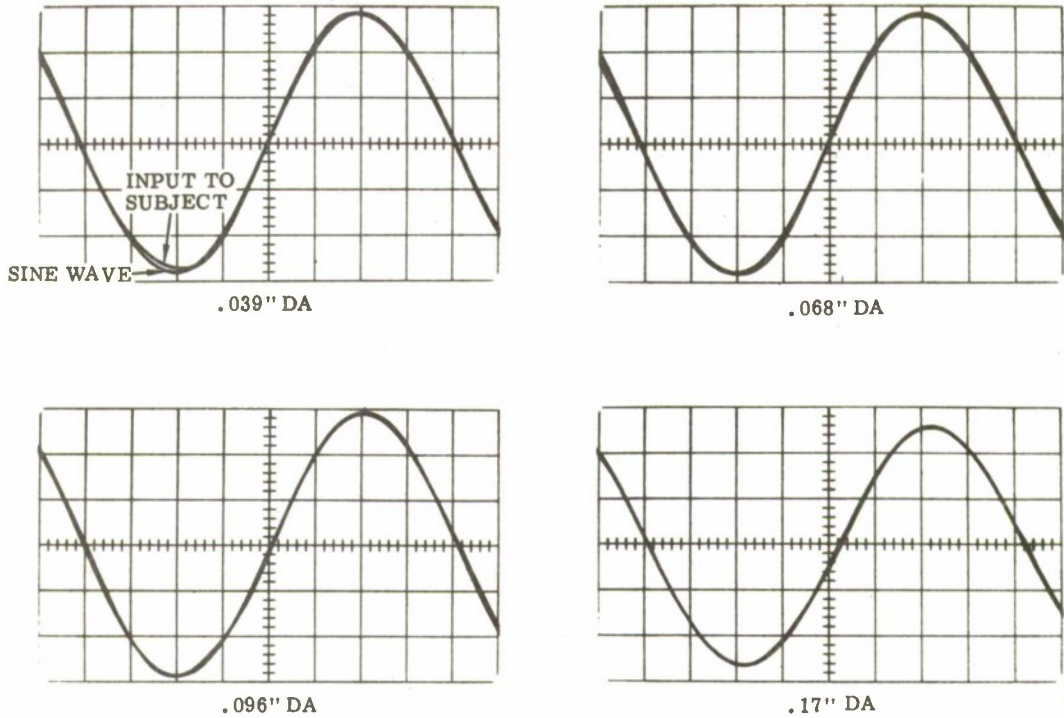


FIGURE 26 16 CPS ACCELERATION CURVE-SINE WAVE COMPARISONS

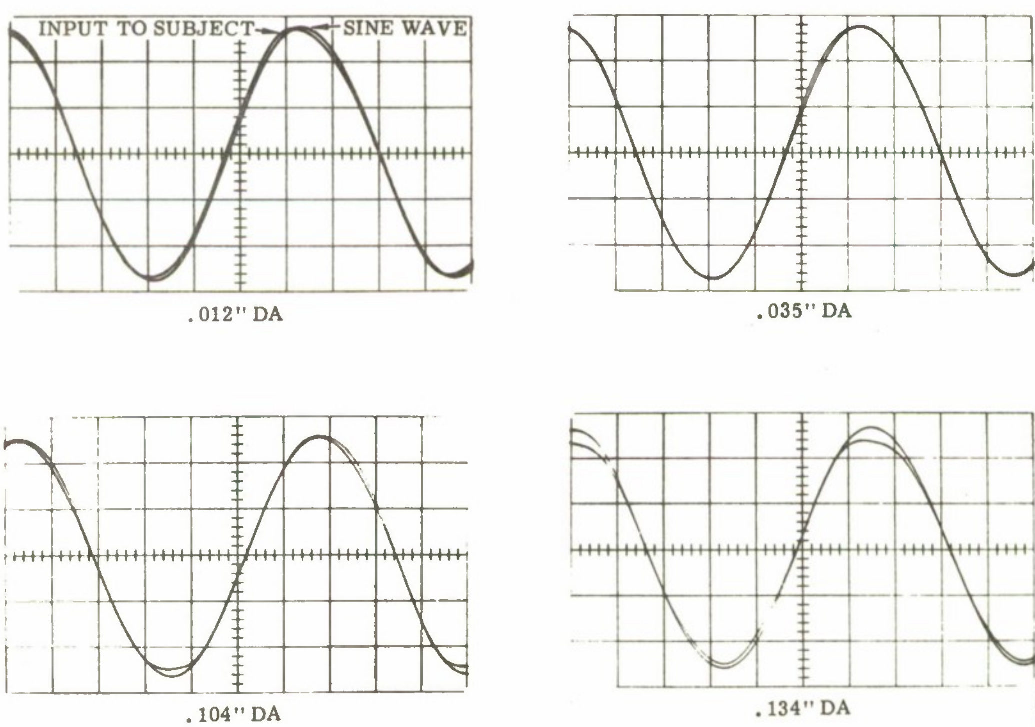


FIGURE 27 20 CPS ACCELERATION CURVE-SINE WAVE COMPARISONS

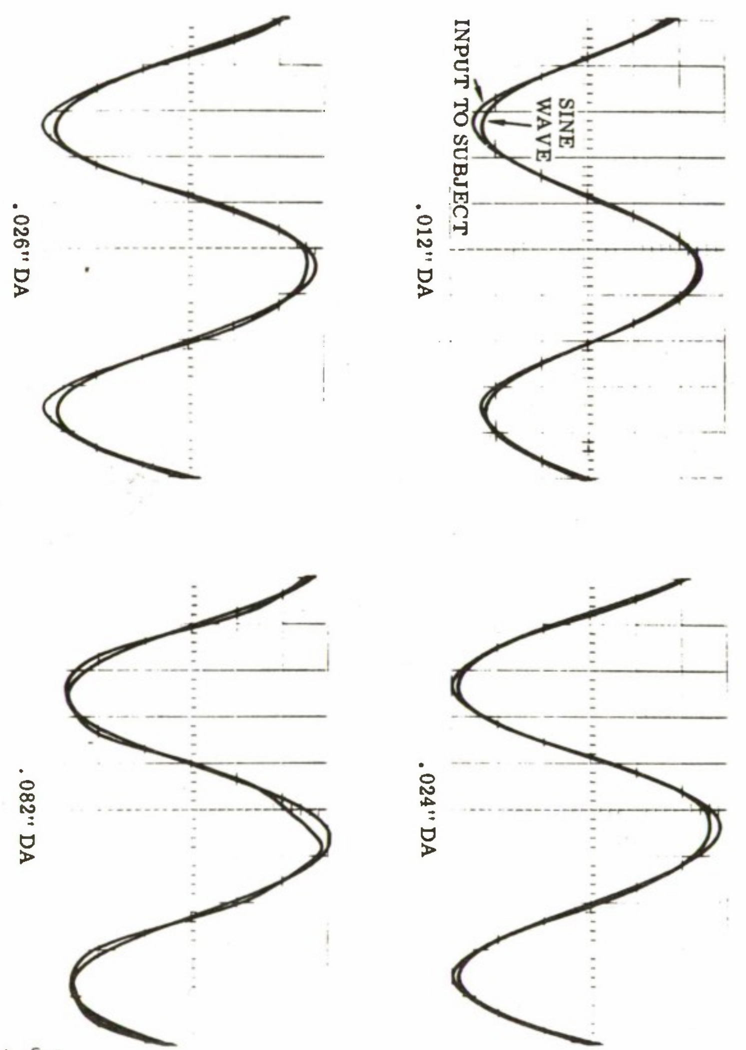


FIGURE 28 27 CPS ACCELERATION CURVE-SINE WAVE COMPARISONS

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Otto Praeger

James D. Solomon

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Paul E. Pearce - Subject preparation and debriefing

James L. Salomon, M.D. - Subject medical examinations, monitoring and analysis

Gilbert C. Tolhurst, Ph.D. - Scientific Officer and Program Monitor for Office of Naval Research

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4. DESCRIPTIVE NOTES (Type of report and inclusive dates): Research on low frequency vibration effects on human performance		
5. AUTHOR(S) (Last name, first name, initial): Chaney, Robert E.		
6. REPORT DATE: August 1965	7a. TOTAL NO. OF PAGES: 59	7b. NO. OF REFS: 4
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13. ABSTRACT

Five male volunteers were utilized in a study of subjective response to vibration while in the standing position. Four reaction levels (perceptible, mildly annoying, extremely annoying and alarming) were established in the range of 1 through 27 cycles per second utilizing the Boeing Human Vibration Facility as the test instrument. Experimental procedures and controls were identical to a previous study in which the subjects were seated.

The annoying levels established were at higher acceleration input values than their counterparts of the seated studies, with only minor variations in the perceptible and alarming curves under the two conditions. Possible explanations of the noted differences, physiological effects of vibration on the standing subject, and body absorption characteristics and their relationship to the subjects reactions are discussed.

DD FORM 1 JAN 64 1473

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Vibration						
Subjective reaction						
Standing vibration						
Human response						
Physiology						
Perception						
Annoyance						
Alarm						

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